

Ram Sagar, Brijesh Kumar, Amitesh Omar

Optical astronomical facilities at Nainital, India

Abstract Aryabhata Research Institute of Observational Sciences (acronym ARIES) operates a 1-m aperture optical telescope at Manora Peak, Nainital since 1972. Considering the need and potential of establishing moderate size optical telescope with spectroscopic capability at the geographical longitude of India, the ARIES plans to establish a 3.6m new technology optical telescope at a new site called Devasthal. This telescope will have instruments providing high resolution spectral and seeing-limited imaging capabilities at visible and near-infrared bands. A few other observing facilities with very specific goals are also being established. A 1.3m aperture optical telescope to monitor optically variable sources was installed at Devasthal in the year 2010 and a 0.5-m wide field (25 square degrees) Baker-Nunn Schmidt telescope to produce a digital map of the Northern sky at optical bands was installed at Manora Peak in 2011. A 4-m liquid mirror telescope for deep sky survey of transient sources is planned at Devasthal. These optical facilities with specialized back-end instruments are expected to become operational within the next few years and can be used to optical studies of a wide variety of astronomical topics including follow-up studies of sources identified in the radio region by GMRT and UV/X-ray by ASTROSAT.

1 Introduction

Aryabhata Research Institute of Observational Sciences (acronym ARIES), an autonomous research institute under the Department of Science and Technology, Government of India, is located on Manora Peak near the city of Nainital (Figure 1). The institute builds and operates observational facilities to carry out frontline research in the areas of Astrophysics and Atmospheric Physics. The institute came into existence on 20th April 1954 as an astronomical observatory under the state government of Uttar Pradesh, India. On 22nd March 2004, the administrative control of the State Observatory was taken over by the Department of Science and Technology, Government of India and it was renamed as ARIES, to signify

the location of Sun in the zodiac ARIES (Ramachandran, 2004; Sagar, 2006) at the epoch of its formation in 1954 and reincarnation in 2004. The present contribution focus on optical astronomy and it gives an overview of the existing observational facilities at ARIES as well as the new initiatives taken up during last decade. The need and importance of new observing facilities in optical astronomy is also described.

2 Manora Peak

The Manora Peak¹ gets about 280 cm of rain annually, of which about 230 cm is concentrated during monsoon months from July to September. The meteorological data indicate that about 150 photometric and 200 spectroscopic nights are expected annually. The seeing at Manora Peak is usually better than 2". The study of extinction properties over 35 years since 1970 (Kumar et al., 2000) indicates that the photometric quality of nights at Manora Peak are stable and there is no noticeable aerosol contamination of the sky. The mean atmospheric extinction values at Manora Peak are 0.57, 0.28, and 0.17 mag airmass⁻¹ in the U, B and V bands respectively, while the corresponding best observed values are 0.45, 0.20 and 0.10 mag airmass⁻¹. The observational facilities at Manora Peak are described below.

2.1 The 0.5m Schmidt telescope

During the International Geophysical year (1957-58), a 79/51-cm f/1 Baker-Nunn satellite tracking camera was installed at the Institute by the Smithsonian Astrophysical Observatory, USA. It was the only center in India but actively networked as a part of the 12 centers established all over the globe. The first photograph of an artificial satellite was taken on 29th August 1958. The camera successfully photographed a total of over 45,700 satellite transits. After 1976, the camera is not in use due to the advent of modern observational techniques in the area. Following successful conversion of such cameras into a wide field Schmidt-telescopes for carrying

Ram Sagar, Brijesh Kumar, Amitesh Omar
Aryabhata Research Institute of Observational Sciences
E-mail: sagar, brij, aomar@aries.res.in

¹ Longitude : 79°27'25" E, Latitude : 29°21'39" N, Altitude : 1927 m



Fig. 1 A panoramic view of Aryabhata Research Institute of Observational Sciences (acronym ARIES) located at Manora Peak, Nainital. The larger white dome houses 104-cm Sampurnanand Optical Telescope which is in operation since 1972.

out astronomical survey work by Australian and Spanish group, ARIES initiated this job in 2005.

The basic optical design of the 79/51-cm f/1 Baker-Nunn satellite tracking camera uses a three-element corrector to produce an extremely wide field of view across a curved plane at the prime focus for photographic imaging. Major jobs in converting the existing Baker-Nunn camera into a 0.5-m Schmidt telescope with CCD imaging capabilities are (i) modification of optical design from photographic curved to flat focal plane for CCD observations, (ii) changing the mounting system from alt-azimuthal to Equatorial English mount (iii) computer control of the telescope, and (iv) optical alignment and installation of a new customized CCD imaging system at the prime focus having plate scale of ~ 7 arcmin per mm. Further technical details can be found elsewhere (Mondal et al. 2009)

The telescope has been successfully installed at Manora Peak in 2011 (see Figure 2) and currently the alignment and fine tuning is in progress. The dome control system has been designed and developed in-house at ARIES. The dome can automatically synchronize with the telescope motion. The computer simulation suggests that the Schmidt camera can reach 20th magnitude with 10% photometric accuracy for an integration time of 1 min. Scientific programs like study of variable stars, Asteroids and Near-Earth-Objects, detection of extra-solar planets though transit method, transient objects like GRBs and supernovae, and imaging of large star clusters could be suitably accomplished with this wide-field imaging telescope.

2.2 The 104-cm Sampurnanand Telescope

The 104-cm Sampurnanand Telescope was supplied by Veb Carl Zeiss, Jena and installed at Manora Peak in 1972. The telescope is a Ritchey-Chretien reflector with a f/13 Cassegrain and f/31 Coude focii. It has an equa-

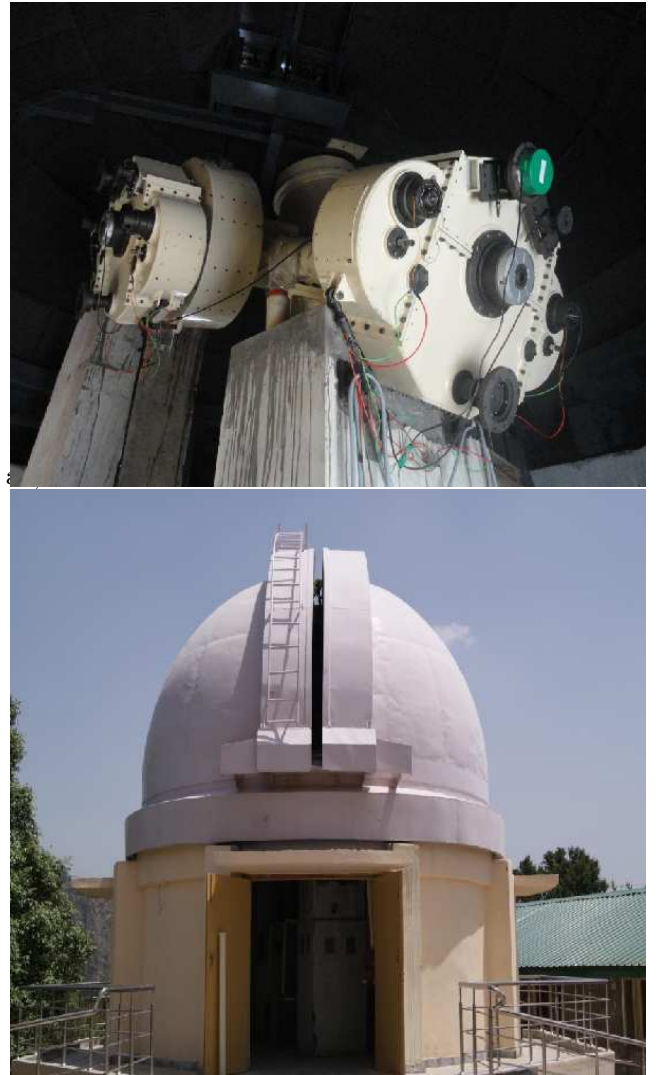


Fig. 2 The 0.51-m Schmidt telescope at Manora Peak. The telescope is shown on top and the dome is shown in bottom panel.

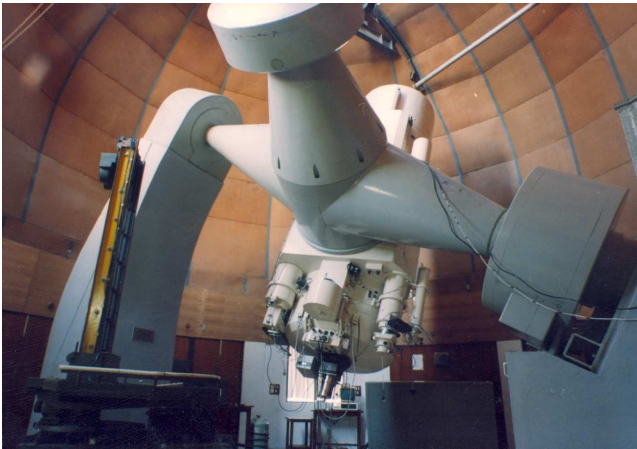


Fig. 3 The 104-cm Sampurnanad Optical Telescope at Manora Peak, Nainital.

torial 2-pier English mount (see Figure 3). A field of 45 arcmin diameter is available with corrector at the Cassegrain focus. During seventies and eighties, the telescope was primarily equipped with a photoelectric photometer and a spectrum scanner. Further technical details can be found in Sinvhal (2006). The guiding of the telescope is done using an ST4 camera mounted with the 8-inch guider telescope and a long exposure (30-min) can be given without trailing. A detailed description of the telescope can be found in Sagar (1999). Currently, the telescope is equipped with a $2k \times 2k$ CCD camera which covers around 13 arcmin of sky, an imaging polarimeter and a three channel fast photometer. Over 650 scientific publications and 40 PhD Thesis have been produced utilizing observational data taken from this telescope.

3 Multi-wavelength observations and role of optical astronomy

The observations of celestial objects at multi-wavelengths are essential to establish their identity and their meaning in astrophysical terms as they radiate across the entire electromagnetic spectrum. For such observations, India has undertaken major initiatives recently, and plans to establish front line observational facilities in future too. For example, Giant Meter-wave Radio Telescope (GMRT) installed during the last decade and the upcoming India's first Multi-wavelength Astronomical Satellite, ASTROSAT are world-class Indian Observing Facilities at radio, X-ray and ultra-violet wavelengths. However, the observing facilities at optical wavelength are far from being world class as all the existing optical telescopes in India² are less than 2.34-m aperture in size while in the

² The existing optical telescope in India includes 2-m Himalayan Chandra Telescope, Hanle; 1.2-m telescope, Mt. Abu; 1.2-m telescope Japal Rangapur, Hyderabad; 2.34-m VBT, Kavalur; 2-m telescope IGO, Girawali near Pune.



Fig. 4 The proposed site at Devasthal for the 3.6m optical telescope.

world moderate (3 to 6 m) size telescopes were established about 3 to 4 decades ago and large (8 to 16 m) ones during the last decade. Now-a-days a number of large (> 8 m) optical telescopes are under fabrication in different parts of the globe. It becomes therefore vital for India to set up moderate size optical telescopes during coming years and plan for larger size optical telescopes in future. Technological advancements and the availability of sensitive detectors have made moderate size optical telescopes not only economical but also extremely valuable even today due to the increased level of performance and minimal maintenance for such systems (Sagar, 2000).

4 Devasthal

An extensive site characterization conducted during 1980 - 2001 in the central part of the Himalayan Range, identified Devasthal (Lat: $29^{\circ}21'40''N$, Lon: $79^{\circ}41'04''E$, Alt: 2450 m above msl) as a potential site for optical observations (Pant et al, 1999; Sagar et al., 2000; Stalin et al., 2001). Seeing measurements close to ground level were successfully carried out on 80 nights during 1998-99 using modern differential image motion monitor. The results indicate a median ground level seeing estimate of about $1''.1$; the 10 percentile values between $0''.7$ to $0''.8$ (mean = $0''.75$) while for 35% of the time the seeing was better than $1''$. Microthermal measurements indicate that if the telescope can be installed above 8 m above from the ground, the seeing could be sub-arcsec. These coupled with the number of yearly spectroscopic nights (~ 210), darkness of the per square arcsec sky ($V \sim 21.8$ mag) and other atmospheric parameters for Devasthal make this site comparable to the international standards (Sagar et al., 2000; Stalin et al., 2001). Devasthal site (see Figure 4) is located about 50 km by road east of Nainital having a direct line-of sight distance (~ 22 km) from the present location of ARIES at Manora

Peak. The upcoming optical facilities at Devasthal are described below.

4.1 The 1.3m optical telescope

In October 2010, a new modern 1.3-m Devasthal Fast Optical Telescope (DFOT) has been installed successfully at Devasthal (Sagar et al., 2011). A picture of the telescope is shown in Figure 5. In order to avoid degradation of seeing due to local environments, the telescope is mounted 3 m above the ground and the enclosure has a roll-off roof design. The telescope design of the 2-mirror Ritchey-Chrétien optics along with a single element corrector is optimized to deliver a fast beam ($f/4$, plate scale of $40'' \text{ mm}^{-1}$) and a naturally flat-field of $66'$ diameter at the axial Cassegrain focus (Melsheimer & MacFarlane, 2000). It is therefore suitable for wide-area survey of a large number of point as well as extended sources. Without autoguider the tracking accuracy of the telescope is better than $0''.5$ in an exposure of 300 s up to a zenith distance of 40° . The pointing accuracy of the telescope is better than $10''$ Root Mean Square (RMS) for any point in the sky. Further technical details on the as-designed specifications of the telescope system are given elsewhere (Sagar et al., 2010, 2012). The main scientific objective is to monitor optical and near infrared (350-2500 nm) flux variability in the astronomical sources such as transient events (Gamma-ray bursts, supernovae), episodic events (active galactic nuclei, X-ray binaries and cataclysmic variables), stellar variables (pulsating, eclipsing and irregular), transiting extrasolar planets - and to carry out photometric and imaging surveys of extended astronomical sources, e.g. HII regions, star clusters, and galaxies. Further details on the scientific objectives can be found elsewhere (Sagar, 2006).

A differential light curve of the WASP-12 transiting system along with the model fit indicates a photometric precision of 1 mmag for a 11.7 mag star. As a comparison, a similar observations using 104-cm Sampurnanand Telescope at Manora Peak, we get an accuracy of about 3 to 4 mmag. Hence the 1.3-m DFOT at Devasthal would be suitable for the scintillation limited science programs requiring a detection of few mmag on a time scale of hrs (e.g. exoplanet search and AGN variability).

A detailed report on commissioning of the 1.3-m DFOT can be found elsewhere (Sagar et al., 2012).

4.2 The 3.6-m Optical Telescope

The 3.6-m optical telescope is a Ritchey-Chretien $f/9$ system. The primary mirror is made from Schott zerodur glass and it is a concave hyperboloid $f/2$ while the secondary is made from Astrosital glass and it is a convex hyperboloid $f/2.6$. The telescope has Cassegrain focus

fitted with a $30'$ wide field three-lens corrector, auto-guiding unit and a derotator instrument interface. The telescope has two side and one main ports (see Figure 5).

The telescope has an alt-azimuth mount and the bearings of the telescope uses latest technology available in the market. The tracking performance of the telescope is better than $0''.1$ RMS for one minute in open loop with winds inside the dome of less than 3 m s^{-1} and in close loop it is $0''.11$ for less than one hour. In open loop and for wind inside the dome of 5 m s^{-1} the tracking accuracy is $\sim 0''.5$ peak in 15 minute. The maximum selwing speed of the telescope is 2° s^{-1} and 1° s^{-1} in azimuth and altitude respectively.

The optics of the telescope are designed and polished to deliver images with encircled energy of 80% in less than $0''.45$ diameter in a $10'$ arcmin Field of View (FoV) over 350 nm to 1500 nm wavelength range without corrector. A preliminary speckle imaging tests performed at the AMOS workshop suggest that the as-built optics can deliver images with E80 better than $0''.3$ diameter (Ninane et al., 2012).

The telescope will be housed in a cylindrical dome like structure having height of 21.5 m and a diameter of 16.5 m. In order to avoid degradation of seeing due to dome, two separate ventilation ducts, one from telescope floor and another from telescope technical room have been provided. An auxiliary building housing aluminising plant from mirrors up to 3.7m diameter have alos been envisioned. More details on the telescope dome and the auxiliary building can be found elsewhere (Pandey et al., 2012).

The first generation focal plane instruments are a Faint Object Spectrograph and Camera (FOSC) and a CCD optical imager. The second generation instruments include an optical near-infrared spectrograph and imager; a high resolution optical spectrograph and an integral field unit.

The Faint Object Spectrograph and Camera (FOSC) is a focal reducer instrument. The instrument will have imaging capabilities with one pixel resolution of less than $0''.2$ in the FoV of $\sim 14' \times 14'$ of the telescope, and low-medium spectroscopy with spectral resolution (250-4000) covering the wavelength range from 350 nm to 900 nm. A computer simulation indicate that we can image a 25 mag star in V band with an hour of exposure time. The optical and mechanical design of the instrument has been completed in-house at ARIES. Further technical details can be found elsewhere (Omar et al., 2012).

An optical imager with a $15\mu\text{m}$ pixel of square size, $4k \times 4k$ back-illuminated CCD detector, liquid nitrogen cooling, full frame window mode operation, and the associated control electronics has also been proposed as a first light instrument. A contract for assembly and integration of the CCD camera has been awarded to Semiconductor Technology Associates, USA³. The mechanical interface

³ <http://www.sta-inc.net/>

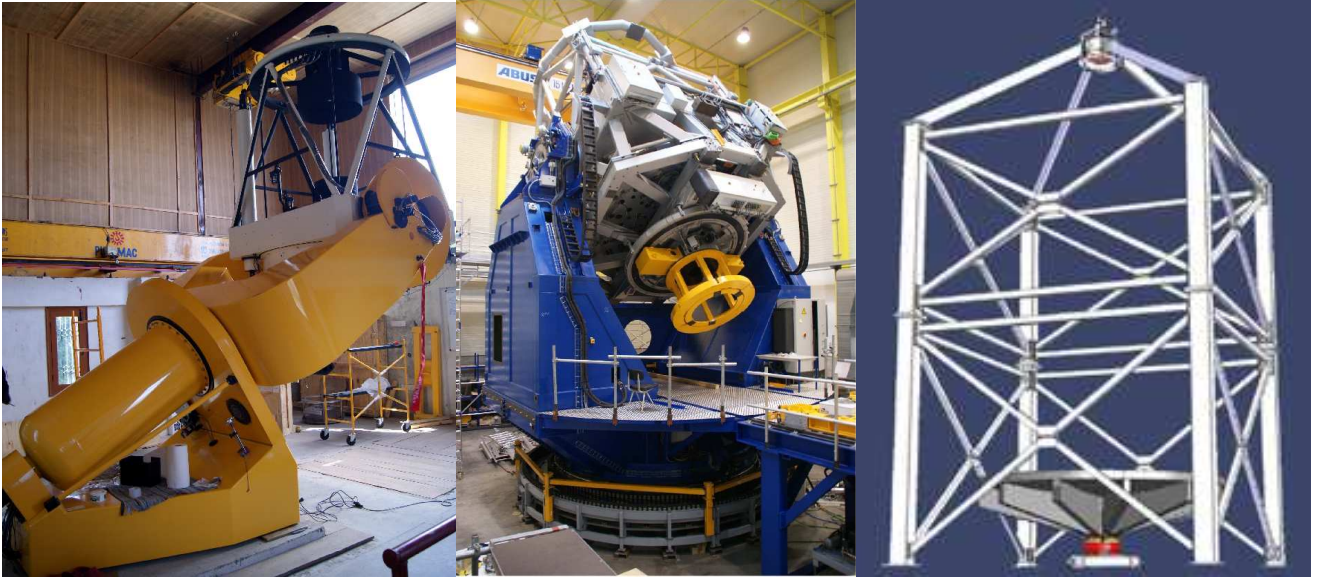


Fig. 5 The 1.3m, f/4 Optical Telescope, installed at Devasthal site (leftmost), the 3.6m, f/9 optical telescope, as-built system at the AMOS workshop, Belgium (middle), and the 4-m, f/2 International Liquid Mirror Telescope, computer rendering of the design (rightmost).

for the camera is being designed and manufactured in-house at ARIES. This imager will primarily be used to verify the performance of telescope during the commissioning phase. The imager will cover a square area of $6'5 \times 6'5$ on the sky. This instrument will have broadband Johnson-Cousins *UBVRI* and *ugriz* SDSS filters, as well as a few narrow-band filters.

The above mentioned focal plane instruments shall be used to carry out observations for the studies related to exo-planets, stellar variability and asteroseismology, interacting binary systems, variability in latest type soft x-ray stars, formation and evolution of stars, studies of galaxies, dark matter in the galaxy, optical follow-up of the sources identified by GMRT and ASTROSAT and the highly energetic events - SNe and GRBs.

4.3 The 4-m International Liquid Mirror Telescope

The 4-m International Liquid Mirror Telescope (LMT) uses Liquid Mirror Technology and the mercury mirror of the telescope will have a diameter of 4 m and a focal length of 8 m (see Figure 5). The ILMT is proposed to be installed at Devasthal as a joint collaboration between India, Belgium and Canada. It will perform as a transit telescope. A $4k \times 4k$ CCD detector with a square size pixel of $15 \mu m$ shall be positioned at the prime focus of the telescope and it will cover an area of about $30' \times 30'$ on the sky. The mirror being parabolic in shape needs a corrector to get a flat focal surface of about $30'$ diameter. The rotation of the Earth induces the motion of the sky across the detector surface. The CCD detector works in a time delay integration mode, i.e. it tracks the stars by

electronically stepping the relevant charges at the same rate as the target moves across the detector, allowing the integration as long as the target remains inside the detector area. At the latitude of Devasthal, a band of half a degree covers 156 square degrees out of which 88 square degrees being covered at high galactic latitude ($b > 30^\circ$) including the direction of the north galactic pole. The nightly integration times are rather short, typically 120 s but it is possible to co-add data from selected nights in order to get sky images of longer integration times. About 10 Gigabytes of data will be collected each night.

The expected 5σ limiting magnitudes achieved by co-adding scans are 24.5 at *U*, *B* and *V* bands, 23.5 at *R* and *I* bands and 22.3 at Gunn-*z* band. The expected database towards the Galactic Bulge direction includes 10 million stars, 30000 variables, 8000 binaries, 8000 LPVs/SRVs, 5000 spotted RSCVn, 1400 RR Lyrae, 250 δ -Scuti, 20 Cepheids, 50 yr^{-1} microlenses and 5 yr^{-1} Cataclysmic variables - providing valuable inputs for the studies of stars, galaxies and cosmology. More details on the 4-m ILMT can be found elsewhere⁴.

5 Summary

The technological advancements and the availability of sensitive detectors has made moderate size, 2-m to 4-m class, optical telescopes extremely valuable even today. Furthermore, such telescopes have advantages over large ones in availability, survey and follow-up work. In next few years a 3.6-m optical telescope with active mirror

⁴ <http://www.aeos.ulg.ac.be/LMT/>

technology and another 4-m telescope with liquid mirror technology will become operational at Devasthal. All these facilities at Devasthal will be valuable addition to the existing optical astronomical facilities in India as well as in the globe.

Acknowledgements The work presented here is on behalf of a larger team associated with the development of Devasthal Observatory. The authors are thankful to the Devasthal Observatory staff for their assistance during observations taken with 1.3-m telescope. Approvals and encouragements to initiate the above projects from all the members of the Governing Council of ARIES are gratefully acknowledged. Useful scientific inputs from members of ARIES project team are thankfully acknowledged.

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